Deconvoluting Lake Pepin Sediments Through Ferrimagnetic Concentration Analysis

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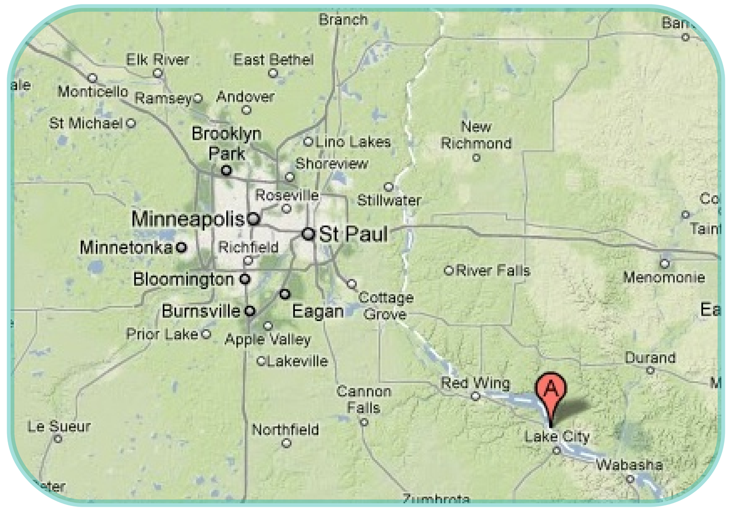
Introduction

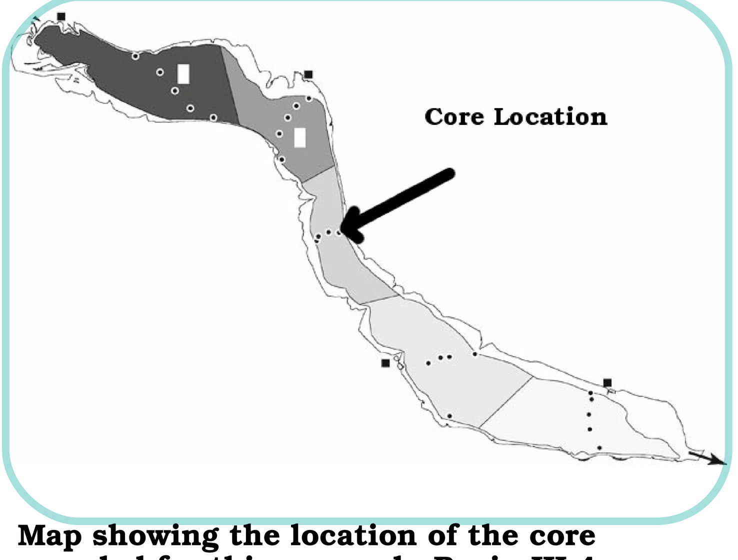
Situated about 60 miles south of the Twin Cities, Lake Pepin is a valuable natural and cultural resource that offers a unique perspective on the history of southern Minnesota. Though Lake Pepin is an impoundment of the Mississippi, it accumulates sediment from the two additional major rivers in the region: the Minnesota and the St. Croix. The sediments deposited in Lake Pepin therefore act as a microcosm of the region, providing an unequaled record of the development of the rivers as well as their recent changes due to human activity.

A study of Lake Pepin was recently performed by colleagues at the St. Croix Watershed Research Station to assess the state of Lake Pepin prior to and following human settlement. This study found that sediment accumulation rates had increased dramatically since the 1850's, especially after 1950[1]. From this arises an important question: where is all the sediment coming from? A number of suggestions have been offered, from simply increased sediment influx into the river to the changing nature of storage in the floodplain due to human structures such as dams and bridges. The goal of my research was to come closer to pinpointing the cause of the Lake Pepins rapidly aggrading sediments.

In order to analyse the sediments in Lake Pepin, I implemented a new model proposed by Ioan Lascu of the Institute for Rock Magnetism for deconvolution of sediment sources based on dry, room temperature magnetics measurements[2]. The model allows for the separation of the magnetic minerals in the sediments into three end members: Uniaxial Non Interacting Single Domain, Interacting Single Domain, and Multi Domain. The origins of these are in turn interpreted as biogenic, pedogenic, and sub-surface. This allows for differentiation between in lake, field, and non-field sources, which should bring us closer to precisely identifying the nature of the sediment pouring into Lake Pepin.



Map showing Lake Pepin relative to the Twin Cities



Map showing the location of the core sampled for this research, Pepin III.4

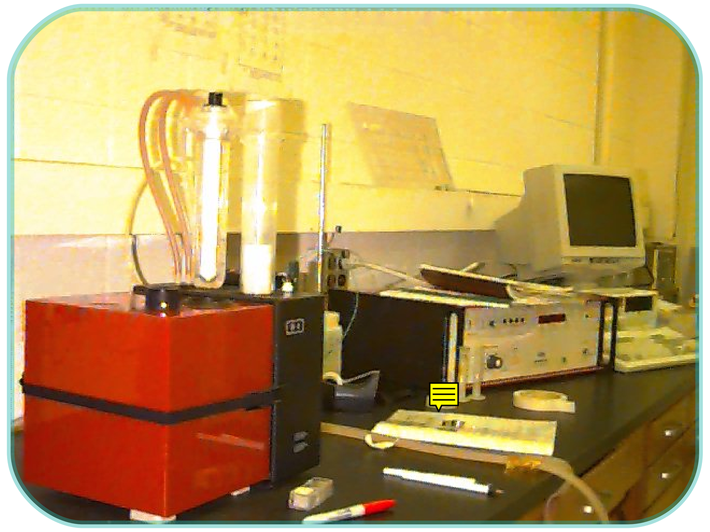
The author taking a surface core very similar to the one analyzed. Dan Engstrom of the SCRWS seals in the bottom.

Methods

The ferrimagnetic concentration analysis was performed on a 1.86 m surface core (Pepin III.4) taken using polycarbonate tubing and a rigid drive rod as part of the previously mentioned Lake Pepin study. The location of the core is specified in the graphic at right. The core had been previously sampled into 2 cm intervals and freeze dried. This made it ideal for the room temperature, dry sample analysis that is specified by the model used.

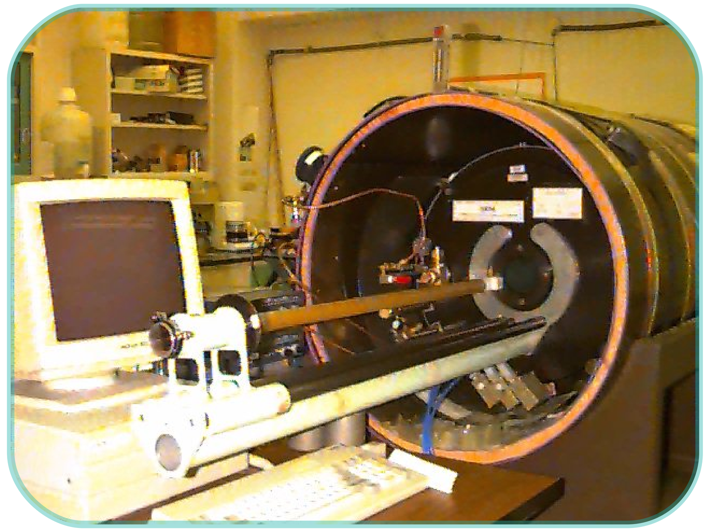
Magnetic properties were measured at the Institute for Rock Magnetism at the University of Minnesota. Sediment from each interval was packed into plastic boxes and massed, allowing the data to be mass normalized. The sediment laden boxes were then run through a series of machines going from low power to high power magnetic fields.

Bulk magnetic susceptibility (X m3/kg) was found using a Geofyzika KLY-2 KappaBridge AC Susceptibility Bridge, measuring the base susceptibility of the sediments in the Earth's magnetic field. Following this, the samples were processed in the Alternating Field de-magnetizer with pARM device. This demagnetized the samples using an AC field in the presence of a low power (5mT) DC field, giving the samples anhysteretic remanence magnetization (ARM). The remanence (Am2/kg) was then measured in the 2-G Superconducting Rock Magnetometer (SRM). The samples were now ready to move onto bigger and better fields, and were placed in the Pulse Magnetizer. They recieved three pulses at 200 mT and the remanence was again measured in the SRM. The sediments were then thrice pulsed at 1000 mT and the remanence subsequently measured. For their grand finale, the samples were processed in the Princeton Measurements micro-VSM, running the samples in a loop up to 1000 mT in order to determine their hysteresis parameters: saturation magnetisation Ms, (Am2/kg) and remence magnetisation Ms (Am2/kg). The samples were then de-magnetised using the VSM to find their coercivity Bc (mT) and remanence coercivity Bcr (mT).

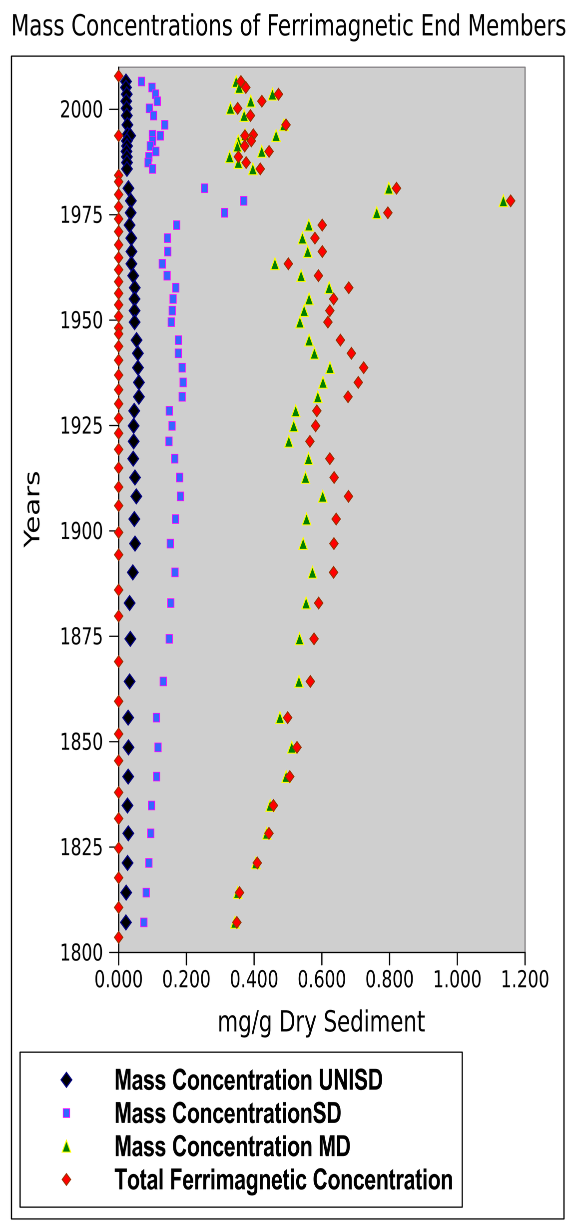


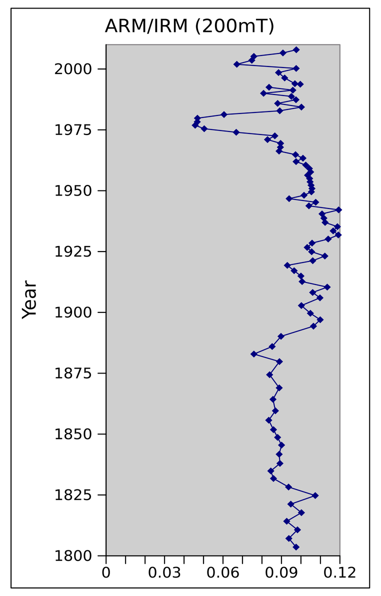
Geofyzika KLY-2 KappaBridge AC Susceptibility Bridge

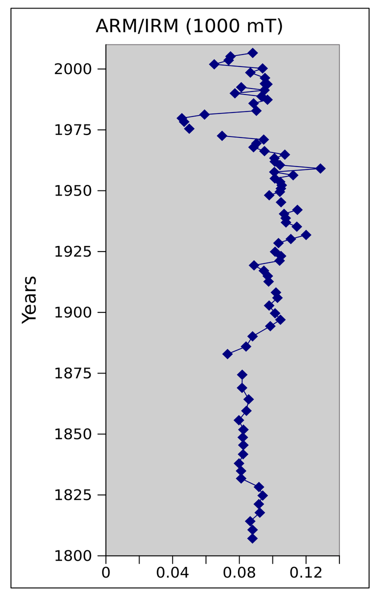
Princeton Measurements micro-VSM

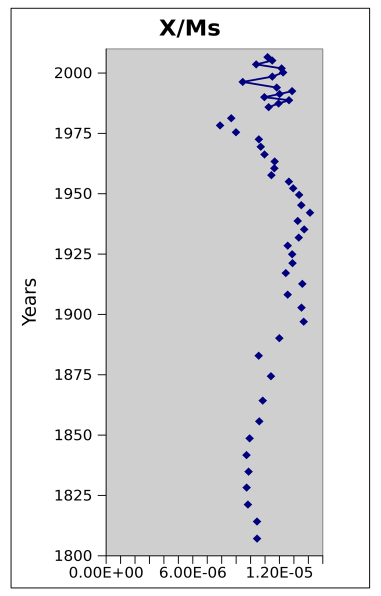


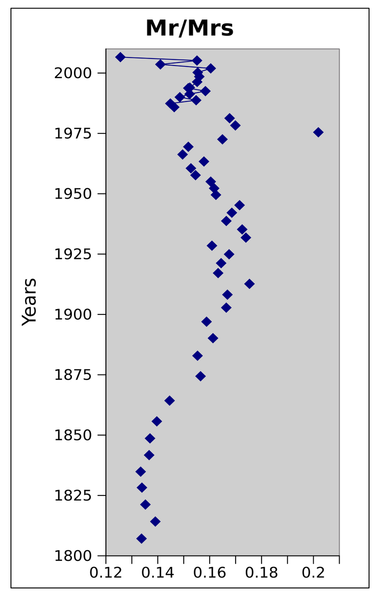
2-G Superconducting Rock Magnetometer











Graphs

Furthest left graph shows changing concentrations in the three end members over time. Note the peak around 1975. The zero values indicate samples that were skipped in VSM processing.

Going clockwise from top left, the **ARM/IRM (200 mT)** and **ARM/IRM (1000 mT)** graphs are very similar, due to the consistency between the two different IRM levels. This is because the magnetics are mostly controlled by a single grain type. Following this is the anomalous **Mr/Mrs** graph which shows a peak at 1975, as opposed to a trough. This shows in increase in finer grained ISD particles. Finally, the **X/Ms** graph shows the proportion of ultrafine particles.

Dan Engstrom and Dylan Blumentritt ponder the nature of lake sediments

A recovered lake core, ready to be stored and sampled

Results

The data gathered was combined and then put through the model proposed by Lascu, Banerjee, and Berquo (in press), who graciously provided a spreadsheet which handled the calculations. As mentioned earlier, the magnetic minerals were separated into three end members (UNISD, ISD, and MD) which were interpreted to be representative of three general sources, in-lake, field, and non-field. The shifting concentration of these sources yields significant historical data from Lake Pepin, particularly after human settlement.

Overall, the data shows a general increase in ferrimagnetic concentration following human settlement, which began occurring in the 1830's and dramatically increased in the 1850's. Biogenic magnetic minerals (UNISD) show a slight decrease in concentration over time, but their concentrations are relatively low; further work will need to be done to determine their impact. Of particular interest is a sharp spike in ISD particles in between 1970 and 1975, shown in the graphs at left. This is then followed by a slight overall decrease in concentration, dropping below 1970 levels.

In examining the magnetics data, there are a few important ratios which act as indicators of certain properties of the magnetic minerals in the sediment. These include ARM/IRM (200 mT), ARM/IRM (1000 mT), X/Ms, and Mr/Mrs. Focusing on the '70/'75 peak, all but one of these ratios shows a sharp drop, Mr/Mrs.. Also significant is the IRM (200 mT)/IRM (1000 mT) ratio, which held steady throughout the length of the core.

Discussion

The results of this research lead to few conclusions, but give rise to many questions and future projects. The increase in ferrimagnetic particle concentrations over time could be due increased erosion of more highly magnetic soils and banks. Another possibility is the human use of magnetic minerals in industry, as well as the tendency for people to use rivers for waste disposal. Extending on this line of thought, the '70/'75 spike might be interpreted as being some massive influx of industrial waste, released in a buildup to the implementation of the Clean Water Act. Much more extensive research would have to be done on Lake Pepin and upstream in order to make any sort conclusive determination on this subject. If the spike were found to be common, it could be used as a dating proxy within the southern Minnesota basin.

The inverse shape of the Mr/Mrs. ratio compared to the other graphs is revealing, indicating an increase in finer grained, interacting single domain particles. With more analysis, this could be used to determine what exactly caused the observed peak at 1975. The IRM (200 mT)/IRM (1000 mT) ratio is used as a proxy for mineral content, and in this case its steady nature shows that the magnetic properties of the sediment are mostly controlled by one grain type, currently interpreted as fine grained magnetite.

Though the results provided by the use of the implemented model are valid, the model could be further calibrated in order to more precisely classify the sediments. This would involve examining lakes fed by only one type of sediment source and using the magnetic properties of these as background data to more precisely fit the model to a certain region or system. Fortunately, due to the flexibility and speed of the model, as well as the plethora of lake cores previously collected for other research available, this should be a feasible and worthwhile task. With further calibration of the model, an accurate picture of many lakes that would otherwise be difficult to analyse could be found with relative ease, which would certainly be a powerful tool on any limnologists belt.

References

1. Engstrom D, Almendinger J, Wolin J (2009) Historical changes in sediment and phosphorus loading to the upper Mississippi River: mass-balance reconstructions from the sediments of Lake Pepin. J Paleolimnol. doi:10.1007/s10933-008-9292-5
2. Lascu I, Banerjee S, Berquo T (2010) Quantifying the concentration of ferrimagnetic particles in sediments using rock-magnetic methods. In press.

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